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SEMIANNUAL REPORT

OF THE

HAYSTACK OBSERVATORY

NORTHEAST RADIO OBSERVATORY CORPORATION

15 January 1972

Operated under Agreement with

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

ACKNOWLEDGMENT

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The Planetary radar investigations are supported under Grant NGR 22-174-003 from the National Aeronautics and Space Administration.

Radar studies of the moon are conducted under Contract NAS 9-7830 with NASA Manned Spacecraft Center, Houston, Texas.

FOREWORD

Beginning with this report, work at Haystack will be summarized semi-annually instead of quarterly, in accord with a recent decision by the Haystack Observatory Office of Northeast Radio Observatory Corporation.

This decision was based upon a need for economy in publication costs and on the opinion that continuing work will receive more coherent treatment when a longer period is covered by the report.

ABSTRACT

As of 31 December, there were 16 active programs in radio astronomy by investigators from 8 institutions. Of these, three are Very-Long-Baseline Interferometer projects, ten are spectral line investigations, one involves continuum mapping in the 0.8 cm region and one is the monitoring of variable sources.

The loan to Haystack of a low-noise mixer developed at BTL, Holmdel, New Jersey, has now made it possible to exploit the potential of the antenna in the 27-42 GHz frequency region. Mapping observations of 3C273 at 31 GHz have shown a good pattern for the Haystack antenna four years after the rerigging of the surface contour for closer tolerance. The new mixer was also used in the detection of a new methyl alcohol line at 36,169 MHz in Sgr B2.

The new Mark II VLBI recording terminal was used for the first time in galactic H_2O source observations using Haystack and the Crimean Observatory, USSR. One feature in W49 appears to have a diameter of 0.3 millisec of arc and a brightness temperature of 1.4×10^{15}° K. Geodetic measurements via VLBI are also proving most promising. Baseline measurements between Green Bank and Haystack have been mutually consistent - and with independent special surveys - within a few meters, and accuracies much less than 1 meter seem possible.

Radar investigations of Mercury, Venus and Mars have continued. The Mars work is of particular interest, since the favorable opposition, together with improvements in the radar, have permitted measurements on a number of topographic features with unprecedented accuracy, including scarps and crater walls.

In the lunar radar work we have emphasized data reduction and improvement of observing techniques rather than observations. It is of interest that the floor of Mare Serenitatis exhibits an upward slope towards the northeast and is also the location of one of the stronger gravitational anomalies thus far measured.

During July through December 1971, radio astronomy observations have used the antenna for 1957 hours while radar studies of the moon and planets occupied 552 hours - an unusually heavy radar schedule. Maintenance and improvements required 440 hours.

NORTHEAST RADIO OBSERVATORY CORPORATION

A nonprofit corporation of educational and research institutions formed in June 1967 to continue the planning initiated by the Cambridge Radio Observatory Committee for an advanced radio and radar research facility. In March 1969, by agreement with MIT and Lincoln Laboratory, its interest was extended to the existing Haystack Research Facility to seek means of increasing its availability for research. Since July 1970, NEROC has directed the research at Haystack and has had the primary role in arranging for support.

NEROC Institutions

Boston University
Brandeis University
Brown University
Dartmouth College
Harvard University
Massachusetts Institute of Technology
Polytechnic Institute of Brooklyn
Smithsonian Astrophysical Observatory
State University of New York at Buffalo
State University of New York at Stony Brook
University of Massachusetts
University of New Hampshire
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CONTENTS

	Abstract	iii
	Northeast Radio Observatory Corporation	iv
I.	Introduction	1
II.	Radio Astronomy	
	A. Summary of Programs	1
	B. Accounts of Selected Programs	1
	C. Radiometric Instrumentation	12
III.	Radar Astronomy	
	A. Mercury and Venus	16
	B. Mars	16
	C. Lunar Studies	17
	D. Radar Instrumentation	25

APPENDIX - Publications for July-December 1971

HAYSTACK OBSERVATORY

I. INTRODUCTION

The emphasis on observations centered about the most favorable Mars opposition we will see for some time kept the Planetary Radar Box (PR-Box) on the antenna for two long periods: 13 July - 24 September and 9 October - 12 November. The Radiometer Box (R-Box) was on the antenna for the remainder of the period from 1 July through 31 December 1972.

During the six months period, 1957 antenna hours were used for radio observations while radar work occupied 552 hours - an unusually heavy radar schedule. Maintenance and improvements required 440 hours.

II. RADIO ASTRONOMY

A. Summary of Programs

During the July - December period, Haystack Observatory accepted 16 new proposals for observing programs. Two of these were for continuum measurements, four were for VLBI observations, and 10 were for spectral-line observations. These last included seven recombination-line programs, and three for monitoring and extending the search for molecular transitions previously seen. Twenty projects were completed while one approved proposal was withdrawn, due to unforeseen tuning restrictions on a paramp.

Programs active as of 31 December are listed in Table I, while concluded programs are listed in Table II.

B. Accounts of Selected Programs

In the following subsections we present sketches of a few programs representative of the radiometric research at Haystack. These summaries were edited by the Observatory staff from the investigators' notes and preprints, and apologies are offered in advance for any unintentional changes in emphasis or other alterations.

TABLE I

Continuing Radio Observing Programs

31 December 1971

PROGRAM	INVESTIGATORS	INSTITUTIONS	THIS ½ Yr. OBS. HRS.	TOTAL HRS. REQUESTED	DESIGNATION
8 & 15-GHz Monitoring of Quasars & Seyfert Galaxies	W. A. Dent	Univ. of Mass./Amherst	374	50/month	DENT-1
7.79-GHz Recombination Lines, Search of Planetary Nebulae	L. E. Goad	Harvard College Observatory	51	72	GOAD-1
28 to 38-GHz Continuum Mapping Observations	G. T. Wrixon	Bell Telephone Laboratories	0	75	WRIXON-2
7.793 GHz-Mapping of H94α Transition in W43	K. Y. Lo E. J. Chaisson	MIT Harvard College Observatory	57	50	LO-1
7.79-GHz Recombination Lines in Sgr B2	E. J. Chaisson C. A. Gottlieb J.A. Ball A.E. Lilley	Harvard College Observatory " " " " " " " " "	0	50	CHAISSON-5
7.81-GHz Observations of C118β Recombination Lines	E.J. Chaisson A.K. Dupree	Harvard College Observatory " " "	49	72	DUPREE-2
22.235-GHz Measurement of H_2O Emission from W49 Signal Statistics	J. M. Moran	Smithsonian Astrophysical Observatory	12	84	MORAN-1
7.85-GHz VLBI Observations with Goldstone 210-foot Antenna	T.A. Clark, G.E. Marandino R.M. Goldstein, D.J. Spitzmesser H.F. Hinteregger, C.A. Knight, A.R. Whitney, I.I. Shapiro A.E.E. Rogers	U of Maryland Jet Propulsion Laboratory Mass Institute of Technology Haystack Observatory	67	8 hrs. per 3 Wk. period	VLBI-9
7.85-GHz VLBI with Goldstone 210-foot Antenna	K.J. Kellerman, B.G. Clark J.J. Broderick, D.L. Jauncey M.H. Cohen, D. Schaffer	NRAO Cornell Caltech	18	48 Semi-annually	VLBI-10

TABLE I (Continued)

PROGRAM	INVESTIGATORS	INSTITUTIONS	THIS $\frac{1}{2}$ Yr. OBS. HRS.	TOTAL HRS. REQUESTED	DESIGNATION
23.1 to 25.3-GHz Search for New Sources of CH_3OH & Continued Search for C_2H_4O	A.H. Barrett, K.Y. Lo, R. Martin, K. Bechis	MIT	108	84	BARRETT-10
8.105-GHz VLBI: Haystack-Westford/NRAO Interferometer (4-antenna experiment)	T.A. Clark, C.A. Knight, I.I. Shapiro, A.R. Whitney, A.E.E. Rogers	NASA/Goddard, MIT, Haystack	0	250	VLBI-13
7.79-GHz Mapping Observations of H94α in NGC 2244	E.J. Chaisson, R. Baldwin	Harvard College Observatory	0	16	CHAISSON-6
7.79-GHz Mapping Observations of H94α in NGC 7538	E.J. Chaisson, C.J. Lada	Harvard College Observatory	16	16	CHAISSON-7
22.235-GHz H_2O Monitoring of Sources & Search for New Sources	J.A. Ball, D.F. Dickinson, A.H. Barrett, K. Bechis	Smithsonian Astrophysical Observatory, MIT	213	70/month	BARRETT-11
16.6-GHz Observations of 73 Recombination Lines in HII Regions	G. Papadopoulos, K.Y. Lo, E.J. Chaisson	MIT, Harvard College Observatory	137	120	PAPADOPOULOS-2
8.105-GHz Haystack-Westford Baseline Calibration	C.A. Knight, A.R. Whitney	MIT	0	32	*WESTACK CAL.

* Haystack - Westford radio interferometer is designated WESTACK;
Haystack - Westford radar interferometer is called HAYFORD.

TABLE II

Observing Programs Completed

1 July - 31 December 1971

PROGRAM	DESIGNATION	INVESTIGATORS	INSTITUTIONS	TOTAL OBS. HRS.
23-GHz Measurements of Linear Pol. in Taurus A	MATVEYENKO-1	L.I. Matveyenko M.L. Meeks	Institute for Space Research, USSR Haystack Observatory	19
7.79-GHz Search for H94α in Heiles Cloud No. 2	DICKINSON-6	D.F. Dickinson E.J. Chaisson	Smithsonian Astrophysical Obs. Harvard College Observatory	21
22.235 H_2O-VLBI with NRL (85 ft) & OVRO (130 ft)	VLBI-11	J.M. Moran G.Papadopoulos, K.Y.Lo K. Johnson, P.R. Schwartz, S.H. Knowles E.Hardebeck, H.Hardebeck	Smithsonian Astrophysical Obs. MIT NRL Caltech	116
1.66-GHz OH-VLBI with NRAO (140 ft)	VLBI-12	J. Moran, J.A. Ball W.J. Wilson E. Hardebeck P.R. Schwartz	SAO Aerospace Corp. Caltech NRL	68
7.79-GHz Recombination Line Observations LAB. SESSION, Harvard	CHAISSON-8	E.J. Chaisson	Harvard College Observatory	8
4.83-GHz Observations of Formaldehyde	MYERS-1	P.C. Myers, A.H. Barrett	Mass. Institute of Technology	67
1.62-GHz Observations of the H159α Recombination Line Near Sgr A	LOCKMAN-1	F.J. Lockman, W.A. Dent	U of Massachusetts/Amherst	46
15.5-GHz Mapping of the Galactic Center Region	DENT-3	W.A. Dent, J.E. Kapitzky	U of Massachusetts/Amherst	29
Search for Spectral Lines around 16.7 - 20.1 GHz	GOTTLIEB-4	C.A. Gottlieb, H. Penfield, J.A. Ball; G.D. Papadopoulos	Harvard College Observatory MIT	91
22-GHz Mapping of Galactic Center Region	MEEKS-3	M.L. Meeks Shelley Rogers	Haystack Observatory MIT Physics Department	18

TABLE II (Continued)

PROGRAM	DESIGNATION	INVESTIGATORS	INSTITUTIONS	TOTAL OBS. HRS.
7.8-GHz Recombination Line Studies (94α) of the Following Sources: Tau A, Ori A, NGC 2024, Sgr A, W49 & Diffuse Background	CHAISSON-4	E.J. Chaisson	Harvard College Observatory	96
7.8-GHz Recombination Line Measurements (94α) in the Cygnus X Region	CHAISSON-3	E.J. Chaisson	Harvard College Observatory	35
30 to 39.6-GHz Search for Molecular Spectral Lines	TURNER-1	B.E. Turner, M.A. Gordon G.T. Wrixon	National Radio Astronomy Obs. Bell Telephone Laboratories	165
23.8 to 25.9-GHz Observations of Transitions in Methyl Alcohol	BARRETT-8	A.H. Barrett, J.W. Waters, P.F. Schwartz	Mass Institute of Technology	31
1.6-GHz Observations of OH in Dark Clouds	MYERS-2	P.C. Myers, A.H. Barrett	Mass Institute of Technology	48
23.3 to 24.6-GHz Search for Transitions in Methylamide (CH_3NH_2)	GOTTLIEB-5	J.A. Ball, C.A. Gottlieb, A.E. Lilley, H. Penfield H.E. Radford	Harvard College Observatory Smithsonian Astrophysical Obs.	24
20.2 to 26.7-GHz Search for Transitions in Ethyl Alcohol	GOTTLIEB-6	J.A. Ball, C.A. Gottlieb, A.E. Lilley, H.E. Radford	Harvard College Observatory Smithsonian Astrophysical Obs.	36
22.7 to 26.6-GHz Search for Transitions in NaCl, HC_3Cl, C_2HCl	DICKINSON-5	D.F. Dickinson	Smithsonian Astrophysical Obs.	35
28 to 38-GHz Mixer System Tests, Continuum Mapping	WRIXON-1	G.T. Wrixon J.C. Carter	Bell Telephone Laboratories Haystack Observatory	53
23.1 to 24.9-GHz Search for Transitions in Ethylene Oxide, C_2H_4O	BARRETT-9	A.H. Barrett	Mass. Institute of Technology	17

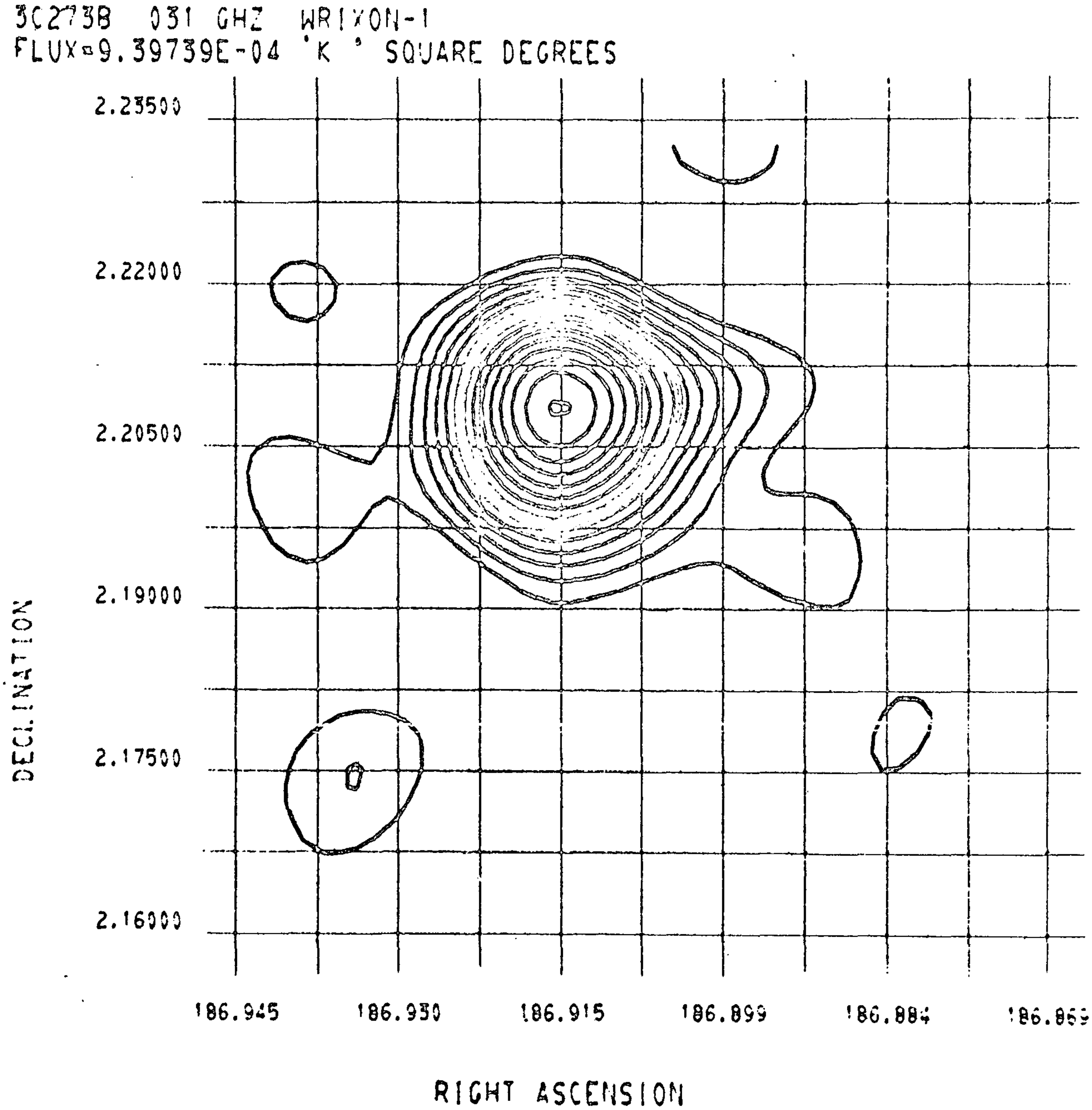

Figure II-1. A contour map of the radio source 3C273 observed at a frequency of 31 GHz. The peak temperature in the observed data is 1.2 degrees K, and the darker contour line represents half of the peak antenna temperature. The data reduction was automated in the CDC 3300 computer. The antenna elevation angle during the measurements was in the vicinity of 41°.

1. Continuum Programs

Preliminary Results of Mapping Observations at 31 GHz

G. T. Wrixon
Bell Telephone Laboratories

M.L. Meeks
NEROC Haystack Observatory

In the frequency range 27 to 42 GHz, a low-noise mixer has been developed at the Bell Telephone Laboratories in Holmdel, New Jersey, by Dr. Wrixon, (see II C 2), and is currently in use on the Haystack antenna. A series of preliminary mapping observations were made to test the performance of the telescope on bright radio sources. These observations as well as mapping observations at 22 GHz (II C 1) disclosed a periodic error in the azimuth servo system with an amplitude of 7 millidegrees peak-to-peak and a period of 1.4 degrees. Although insignificant at lower frequencies, these errors introduced noticeable distortion in the observed shape of small-diameter sources. In December the source of the azimuth errors was determined and the errors were essentially eliminated.

Figure II-1 shows a map of the small diameter source 3C273 at 31 GHz. Although the noise level in this figure is not negligible, the shape of the antenna beam may be seen to be symmetrical with sidelobes less than 15 percent of on-axis gain.

2. Spectral-Line Programs

Low Energy X-Rays Ruled Out as Interstellar Ionizing Mechanism Toward K3-50

E. J. Chaisson and L. E. Goad
Harvard College Observatory

The emission nebula K3-50 was originally catalogued as a planetary nebula, but is now thought to be one of several compact H II regions embedded within a more extended region of thermal emission. Observations by other workers of the 21-cm hydrogen line in the direction of this nebula revealed a massive, rotating condensation of neutral hydrogen gas, the approximate radial velocity of neutral hydrogen coinciding with that of previously measured hydrogen recombination lines. In the present observations 94α recombination lines of H, He, and C, and H 148δ were detected around 7.8 GHz. These spectra were decomposed on the basis of Gaussian line-shape to reveal narrow emission features evidently produced by hydrogen and carbon recombination in an HI region along the line of sight toward the nebula. The fraction of ionized atomic hydrogen is determined to be $(6.8 \pm 5.8) \times 10^{-4}$. In comparison with the neutral 21-cm hydrogen emission, this value implies an HI cloud electron density of $\sim 10^{-3}$. For this cloud, soft x-rays (~100 ev) can be ruled out as the interstellar heating mechanism on the basis of the observed density ratio $n(He^+)/n(H^+) < \sim 0.16 \pm 0.08$.

Observations of Recombination Lines at K_u-Band

G. D. Papadopoulos, K. Y. Lo, P. Rosenkranz
Massachusetts Institute of Technology

E. J. Chaisson
Harvard College Observatory

The recombination line H 73α at a frequency of 16.563 GHz has been observed in four HII regions: Orion A, W3, W49, and W51. These observations were made possible by the loan from MIT Research Laboratory of Electronics of an uncooled degenerate parametric amplifier with a noise temperature of about 120°K and 18 db gain. The overall system temperature for spectral-line observations (single sideband) was 450°K. Recombination-line observations at short wavelengths such as this have the advantage of good angular resolution. They also help to distinguish conditions of local thermodynamic equilibrium (LTE) from non-LTE conditions. The energy level distributions indicated by the present observations are consistent with the predictions of non-LTE theory.

Detection of the 4_1-3_0 (E_2) Transition of Interstellar Methyl Alcohol

B. E. Turner and M. A. Gordon
National Radio Astronomy Observatory

G.T. Wrixon
Bell Telephone Laboratories, Holmdel, New Jersey

Previously observed lines of interstellar methyl alcohol (CH_3OH) in the sources Orion A and Sgr B2 led us to conclude that the excitation of this molecule is anomalous in the sense that there are small population inversions for most or all of the observed transitions. A model for the excitation has been proposed (Zuckerman, Turner, Johnson, Palmer, and Morris: paper to be published in Ap. J.). This model predicts that the $4_1 - 3_0$ (E_2) line at 36169 MHz would be detectable in Sgr B2 but not in Orion A. Predictions also indicated that the $4_0 - 3_1$ (E_1) line at 28316 MHz and probably the $7_2 - 8_1$ (E_2) line at 37704 MHz would not be detectable.

We used the double-ended mixer receiver developed by Wrixon at the Bell Laboratories to check these predictions, all of which were verified. The $4_1 - 3_0$ (E_2) line was detected from two distinct clouds in the Sgr B2 region; the velocities are 53.9 and 70.3 km/s and the spatial separation is about 1 arc minute. No other molecules so far detected in Sgr B2 appear to have a similar distribution. Both features have a strength of ~40 f.u.

Several other molecules were sought in the 28 to 40 GHz range with the Wrixon receiver, without success. Included were cyanamide (NH_2CN) acetaldehyde (CH_3CHO), carbonyl sulphide (OCS), dimethyl ether ($(CH_3)_2O$), sulpher dioxide (SO_2), ethyl cyanide (CH_3CH_2CN), methyl cyanide (CH_3CN), and methyl isocyanide (CH_3NC). For OCS and CH_3CN these negative results, taken in conjunction with detections at other frequencies, are consistent with a thermal excitation.

3. VLBI Programs

High Resolution Measurement of the Angular Size of the Water-Vapor Radio Sources in W49

B. F. Burke, K. Y. Lo, D.C. Papa, G.D. Papadopoulos, and P. R. Schwartz - MIT

L. I. Matveyenko, L. R. Kogan, V. I. Kostenko
Institute for Cosmic Research, USSR

J. M. Moran - Smithsonian Astrophysical Observatory

I. G. Moiseyev, V. A. Efanov - Crimean Astrophysical Observatory - USSR

S. H. Knowles, K. J. Johnson - Naval Research Laboratory

B. G. Clark - National Radio Astronomy Observatory

A. E. E. Rogers - Haystack Observatory

A VLBI experiment was undertaken in June 1971 with two antennas - Haystack Observatory (120-ft) in Westford, Massachusetts, and Crimean Astrophysical Observatory (72-ft) in Semeiz, USSR - in order to observe galactic H_2O sources at a frequency of 22 GHz. For this experiment the length of the baseline was 7375 kilometers or 547 million wavelengths. At each station a signal bandwidth of 2 MHz was recorded on the new Mark II recording terminals, designed and built under the direction of the National Radio Astronomy Observatory.

Subsequent to the observations, the data were processed in such a way that the fringe visibility was measured as a function of frequency with a resolution of 150 KHz (2 km/sec).

Sources in the W49 region were observed over a three-hour period during which the fringe spacing was about 0.38 milliseconds of arc, varying only 6%. The strongest feature in the observed spectrum (radial velocity: -1.8 km/sec) gave a constant fringe amplitude of 0.3 ±0.05 and a flux of 30,000 f.u. These results suggest a source model in which this feature has the form of a uniformly bright disk 0.3 milliseconds of arc in diameter * having an apparent brightness temperature of more than 1.4×10^{15} °K.

Other features with radial velocities near -6 and +6 km/sec showed lower fringe visibilities. Probably this was due, at least in part, to a blending of features and to the low spectral resolution.

Precision Geodesy via Radio Interferometry: First Results

H.F. Hinteregger, R. Ergas, C.A. Knight, D.S. Robertson, I.I. Shapiro, A.R. Whitney - MIT

A.E.E. Rogers - Haystack Observatory

T.A. Clark - NASA Goddard Space Flight Center

Very-long-baseline interferometry experiments involving observations of extragalactic radio sources were performed in 1969 to determine the vector separations between antenna sites in Massachusetts (Haystack 120-ft), West Virginia (NRAO 140-ft), and California (Caltech 90-ft).

For the Massachusetts-West Virginia sites, the 845.130 kilometer baseline length determined from two separate VLBI experiments agreed within 2 meters, and also with the results from a specially-performed geodetic survey. Differences in baseline direction corresponded to discrepancies of about 5 meters. However, the individual group-delay measurements derived from the coherently frequency-switched observations had typical random errors under 1 nanosecond ($< \sim 0.3$ meters).

For the Massachusetts-California baseline, about 4000 kilometers in length, only one experiment was carried out, and the VLBI estimates of the vector components differed by 10 to 20 meters from the survey results. These larger discrepancies are believed due to the low system sensitivity then available at the California site.

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* In contrast, the OH emission points in this region have angular sizes on the order of 50 milliseconds of arc.

Interferometric Observations of an Artificial Satellite

R.A. Preston, R. Ergas, H.F. Hinteregger, C.A. Knight,
D.S. Robertson, I.I. Shapiro, A.R. Whitney
Massachusetts Institute of Technology

A.E.E. Rogers - Haystack Observatory

T.A. Clark - NASA Goddard Space Flight Center

During a VLBI observing program involving Haystack, NRAO/Green Bank, and Cal Tech/Owens Valley Radio Observatory, conducted during October 1969, the TACSAT I communication satellite was observed for a period of seven hours. This satellite, in synchronous orbit, radiated a noise signal with an effective power of 1 kw, over a bandwidth of 10 MHz centered at 7257.5 MHz. The signal was so strong -- nearly six orders of magnitude greater than those from natural celestial sources -- that the low-noise front-end amplifiers were bypassed to avoid saturation.

Processing of data taken simultaneously at the three sites was completed recently, yielding measurements of both differential delay and the rate of change of delay with time. For an individual tape-pair the delay could be determined to 0.15 nanosec and the delay rate to 0.05 picosec/sec, permitting an excellent determination of the satellite orbit. In principle, these measurements demonstrate also the feasibility of highly precise baseline determinations as well. This was not demonstrated here, however, since relative motion between satellite and antennas is required for such a determination and this satellite is nearly geostationary.

C. Radiometric Instrumentation

1. An Antenna Pointing Improvement

Some data taken early this year indicated an azimuth pointing error varying periodically with azimuth and having a 0.007° peak-to-peak amplitude with a period of 1.406° in azimuth. This has been substantially reduced. Remaining is another, but smaller, variation of 0.002° amplitude with a 0.469° period.

High resolution azimuth angle information is obtained from the phase angle of a 1.2207 KHz sine-wave signal taken from the azimuth "Phasolver" transducer. One complete phase angle rotation occurs for every 1.40625° azimuth change. Excitation to the phasolver is provided by four quadrature-related reference signals at this frequency. The large periodic error was corrected by small readjustments of the phase and amplitude relations among these signals.

We believe the remaining smaller and faster oscillation (which, by the way, also exists in the elevation system) to be inherent in the phasolvers.

J.C. Carter
R.P. Ingalls

2. 27-42 GHz Radiometer

Continuum radiometers at 35 GHz have occasionally been used on Haystack. However, their poor sensitivity has limited observations to strong sources such as the sun, moon and Jupiter. A pattern transmitter at the Millstone boresighting location on Pack Monadnock in New Hampshire has also been used in evaluating Haystack at this frequency.

In July, a new continuum radiometer was constructed using a low-noise tunable mixer built by G.T. Wrixon at the Bell Telephone Laboratories. A phase-locked local oscillator was added in October to permit spectral-line observations. The system characteristics using the Wrixon mixer ("Wrixer") are:

Frequency Range: 27-42 GHz

First RF Stage: Mixer

IF Bandwidth: 200 MHz

System Temperature: 1,000 to 1,500° K (Double Sideband)

Signal Feed: Horn, Vertical or Horizontal Polarization

Comparison Feed: Horn, Horizontal Polarization

J.C. Carter

3. K-Band Maser Development

A 22-24 GHz maser amplifier is being developed at Haystack with the collaboration of Professor Sigfrid Yngvesson of the University of Massachusetts, Amherst. U. Mass, Harvard and MIT are each providing some of the required funding for parts, outside shop work and test equipment.

Comments on progress are given below.

Magnet

Evaluation of the superconducting magnet has been carried out. The test header consisted of a room temperature flange and a magnet mounting flange thermally isolated by 3 lengths of .020" wall stainless steel K-Band waveguide. The test unit was equipped with diode helium level indicators. A temperature monitoring resistor was provided at the top end of the magnet for assessing helium hold time and a magneto resistor probe was employed for monitoring magnetic field strength. The magnet was evaluated to a level of 45 amperes without problems. This value is approximately three times greater than that required. To achieve this 45 ampere level, several types of materials were evaluated for thermal isolation and I^2R loss. A further addition to the magnet circuit was the development of a superconducting switch that requires only a few milliwatts of D.C. power to operate. The magnet and superconducting switch were tested at various levels and under different conditions and found satisfactory. All possible magnet circuit parts have been plated or coated to reduce corrosion.

Molybdenum Structure

This unit, several of which have been received, is designed to support the ruby and microstrip transmission lines. Based upon test samples submitted, a plating vendor was selected to nickel and gold plate only one unit. This unit has been received and is awaiting final evaluation.

Microstrip Transmission Lines

Six blanks of 1" x 6" x .025" alumina substrate, metalized with chrome gold and polished to a few microns on both sides, have been delivered. A vendor has been located who will diamond grind these blanks to produce the final shapes required. These six blanks will yield three pairs of microstrip lines (inputs and outputs).

Additional Items

One of the unplated molybdenum structures is being test-fitted with all the parts that comprise the maser unit up to the point where it ties into the header. Now that buffers and other required parts are on hand, the final header design can be undertaken.

L. P. Rainville

4. New X-Band Paramp Installation

Early this year a contract for the development of very-long-baseline interferometry (VLBI) for geodetic applications was concluded between NEROC and the Air Force (with ARPA support). Under this task a new refrigerator-cooled wide-band paramp has been procured from Comtech for use at Haystack during these experiments. Eventually the amplifier will be usable when either the Radiometer Box or the Planetary Radar Box is on the antenna.

Considerable work has already been completed toward the mounting of required components, including the refrigerator compressor, on the Haystack antenna structure. In the R-Box, the old 7.5-8.5 GHz tuned diode continuum radiometer has been removed, and a new front-end waveguide arrangement is ready for the new paramp which is expected shortly.

Construction of instrument packages for use on antennas in California, Alaska and Europe during this program has also progressed well at Haystack.

Personnel concentrating on this work are supported under Air Force Contract F 23601-71-C-0092. (Principal Investigators: Prof. I.I. Shapiro, MIT; Dr. A.E.E. Rogers, Haystack Observatory)

Alan E.E. Rogers
Southard Lippincott

5. Haystack-Westford Interferometer (WESTACK)

Two upcoming radio astronomy programs will utilize the short baseline interferometer between the Haystack antenna and the 60-foot antenna at the Westford Communications Site (MIT Lincoln Laboratory), which was established for 4-cm radar measurements of lunar surface topography. The two radio experiments, one at 8.105 GHz and the other at 22 or 25 GHz, required new receiver arrangements as well as improvements in antenna pointing.

The existing Westford X-Band paramp was improved in stability and tuning range so that both the radar frequency of 7.84 GHz and the VLBI frequency of 8.105 GHz can be accomodated. The phase-locked klystron stalo system was modified so that it could be used in a range of frequencies to accomodate tuning away from the radar frequency. The 120 MHz reference signal from Haystack can now be generated by a frequency synthesizer which can be offset to provide the required tuning range. This requirement is essential for the short baseline interferometer experiments planned. This stalo is also used as an X-Band source for tripling to accomodate the K-Band receiver installed for 22 and 25 GHz work.

The PR-Box K-Band radiometer front end was temporarily relocated at Westford to permit antenna evaluation at this frequency. An offset feed horn constructed at MIT was also installed. The front end output was connected to the Westford moon radar receiver IF chain and thus can be connected to Haystack via the intersite cabling for signal processing.

Pointing and efficiency measurements at 22.2 GHz were carried out by K. Y. Lo of MIT, who showed that the Westford antenna was sufficiently precise to be used near 1-cm. A number of deficiencies in the pointing and servo systems have been isolated or corrected so that it now appears that Westford can be used for radio source tracking at 1-cm.

A computer program was written to provide convenient input settings for the Westford analog celestial coordinate converter. This program takes either current or 1950 RA and DEC and Sidereal time at a start epoch as input and generates current DEC and LHA for input to the coordinate converter at convenient intervals - say every 30 minutes. The converter output in AZ and EL is used to command the Westford antenna.

Phase reference stability for the WESTACK interferometer was improved during the fall by enclosing and insulating the intersite cabling, thus greatly lengthening the time constant of thermal effects upon the phase reference.

R. P. Ingalls
J. C. Carter
A. E. E. Rogers
P. B. Sebring

III. Radar Astronomy

A. Mercury and Venus

The radar box schedule did not favor extensive observations of Mercury, but routine ranging measurements were made of that planet from late July to early September 1971.

A greater effort was directed toward an intensive series of Venus range delay measurements centered about the superior conjunction of 27 August 1971. A total of 21 observations with the 60 microsecond pulse width mode were taken between 15 July and 10 November 1971. Although because of emphasis on Mars results, the data have not as yet been fully analyzed, this gravitational retardation experiment series appears to have more promising results than the observations made about the superior conjunction of January 1970. There was better total coverage of the planetary orbit both before and after conjunction, and the experiment was not plagued with the equipment problems that occurred in 1970. Unfortunately, two days were nonetheless lost right at superior conjunction - one from equipment failure and the other from weather.

An existing on-site computer program was modified to provide sub-radar longitude and latitude as well as limb-to-limb frequency spread for Mercury and Venus. This program (LMDOP2) uses the current IAU definition for the planetary coordinate system. It was checked against independently written computer programs (PLONG and VRPF) that had been generated for Prof. I.I. Shapiro (MIT). This should end a situation in which a number of different coordinate systems had been in use for the analysis and presentation of Venus and Mercury radar data.

R. P. Ingalls

B. Mars

Observations of Mars, begun in April, were continued intensively with the Haystack radar system during the interval mid-July through mid-November 1971. In all, 2044 measurements of round trip echo time delay, surface scattering law, and radar cross section were made of Mars in 1971. From these measurements, it is possible to derive improved orbits for Mars and Earth, and the topography, rms surface slopes, and dielectric constant of the Martian surface for those latitudes and longitudes containing the subearth point at the times of observation.

A preliminary report* summarizing some topographical aspects of the observations has already appeared. A notable characteristic of the 1971 radar observations, as compared to those of 1967 and 1969, was the order-of-magnitude improvement in ranging accuracy resulting from a combination of favorable geometry during the 1971 opposition and improvements in the radar

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* G.H. Pettengill, A.E.E. Rogers, I.I. Shapiro, Science, 174, 1321 (1971).

instrumentation. Where the echo signal is sufficiently strong, it is possible to determine surface heights to an accuracy of ±75 m.

Figures III-1a, 1b, and 1c display the variation in surface height derived in 1971 for 120° sectors of longitude along a constant parallel of latitude at -14.25°, while Figure III-1d covers the same longitude sector as Figure III-1a but at -20.20° latitude. The highest (+7.0 km) and lowest (-7.5 km) elevations encountered on the planet in 1971 are both contained in Figure III-1a. The region from 70°W to about 180°W longitude in Figures III-1a and 1b was observed separately (at very nearly the same latitude) in early August and again in mid-September; both sets of data have been merged in the plots where their excellent agreement may be seen.

Of particular interest is the scarp seen at about 40°W (in Figure III-1a). This feature shows a sharp edge 5 km deep which is reminiscent of some terrestrial slip faults. Another steep slope is evident on the west side of the peak at 120°W in Figure III-1b. Both of the peaks seen near 110°W in Figure III-1a appear to be continuations of elevated topography seen at similar longitudes, but 20° further north, in the 1969 observations. Note the marked difference in shape of the elevated regions in Figures III-1a and 1d, as well as the absence of the scarp in Figure III-1d, despite the fact that the latitudes in the regions of the two figures are only 6° apart.

Reduction of the 1971 Mars radar observations is continuing with emphasis now being placed on solutions for surface rms slopes and dielectric constant.

G. H. Pettengill (MIT)

C. Lunar Studies

Topographic Mapping

Very few new topography observations were made during this period. Rather, work was concentrated on evaluating the several causes of distortion in the calculated elevations and in the location of features on the topography maps.

Lunar ephemerides continue to be one major source of trouble, and a start has been made on converting all operations to use the basic Slade ephemeris and the precise calculations of M. Ash's Planetary Ephemeris Program for topocentric (apparent) lunar positions and velocities. For about a year, all the radar measurements have been set up using such an ephemeris, but the subsequent reduction of the measurements into topography maps has used a combination of Slade's lunar center of mass ephemeris with a locally-generated ephemeris for lunar libration. The latter has been sufficiently in error to cause non-linear (i.e., of higher order than simple slopes) discrepancies between overlapping measurements made at different times, resulting in some wild results from our simple least-squares fitting programs.

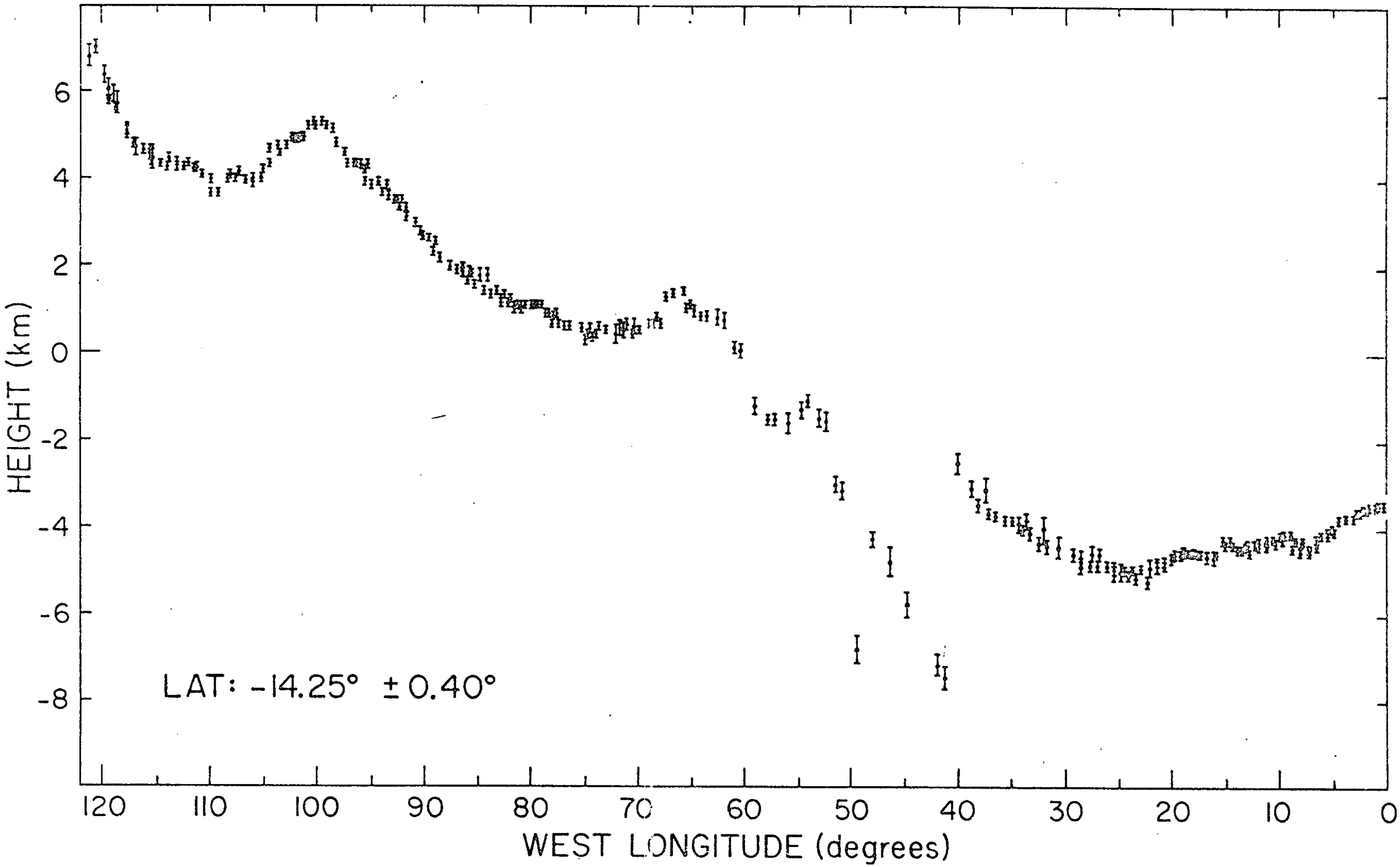

Figure III-1a Martian surface height variations as observed by the Haystack radar at a wavelength of 3.8 cm during July and August 1971. The heights shown are referred to a reference planetary radius of 3393 km, and have been obtained from a least-mean-squares adjustment of the orbits of earth and Mars to best fit all Haystack data obtained in 1967, 1969 and 1971. Error bars correspond to plus and minus 2 standard deviations of the estimated error of measurement.

a Topography at -14.25° latitude between 0°W and 120°W longitude

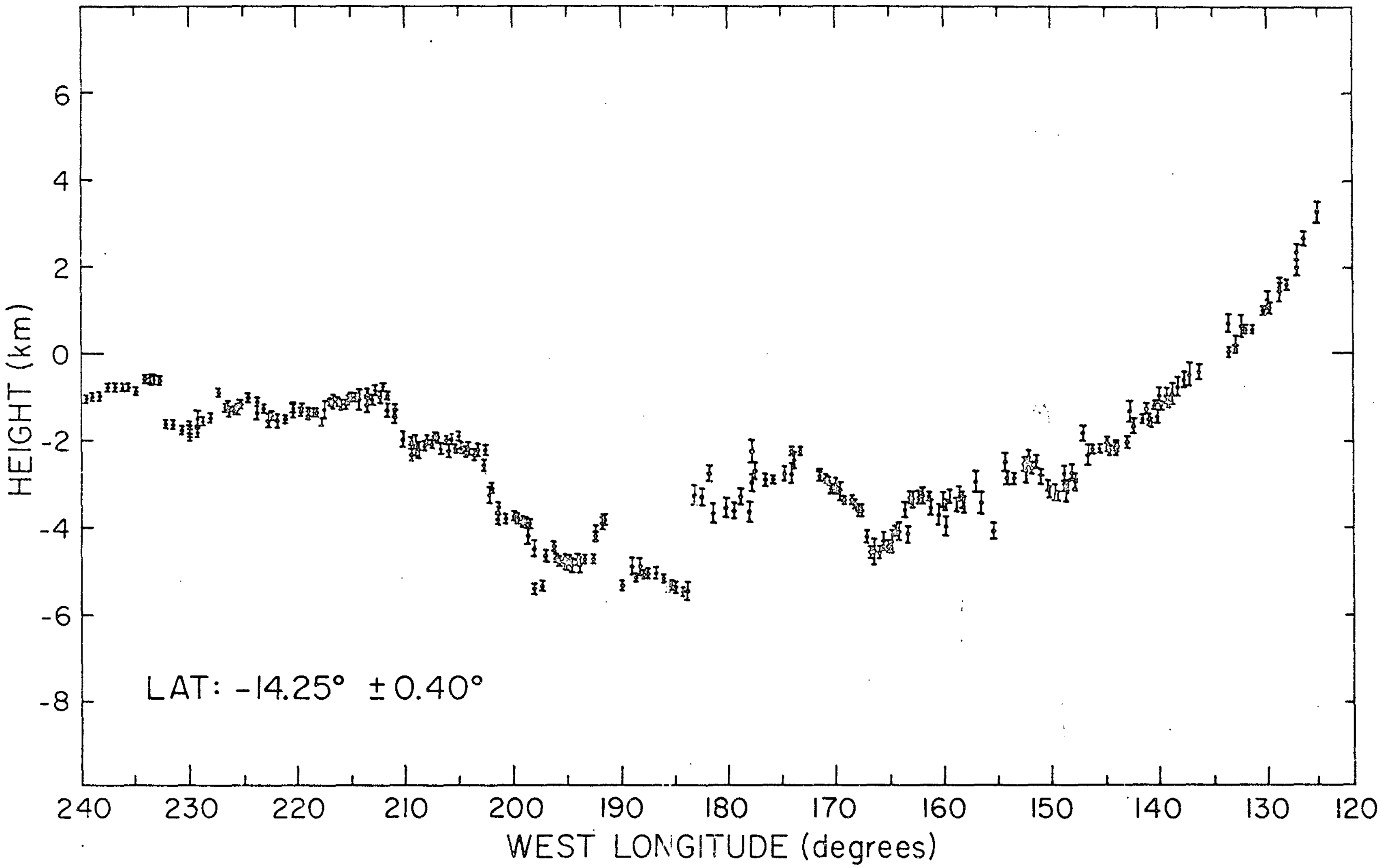

Figure III-1b Martian topography at -14.25° latitude between 120°W and 240°W longitude

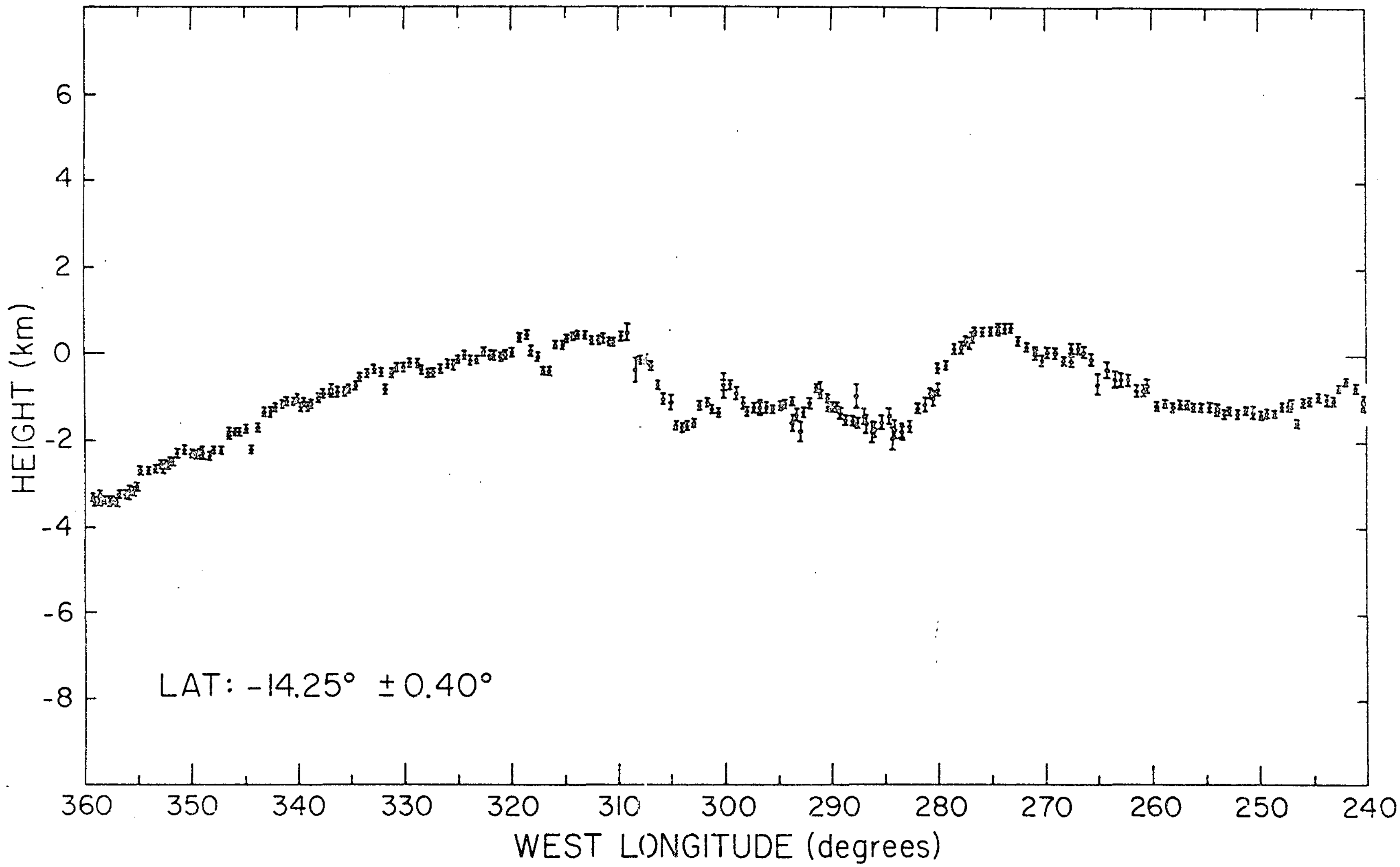

Figure III-1c   Martian topography at -14.25° latitude between 240°W and 360°W longitude.

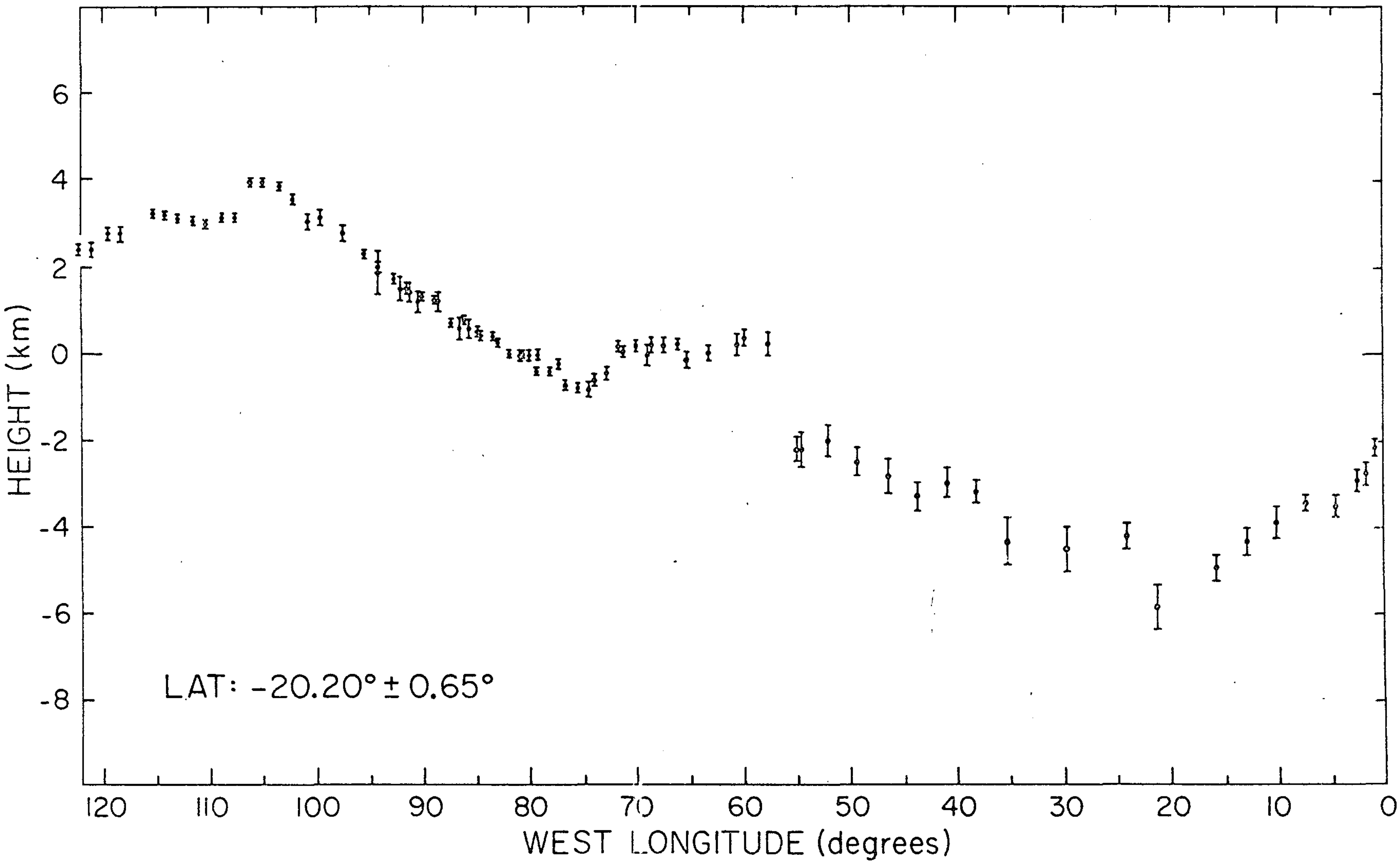

Figure III-1d Martian topography at -20.20° latitude between 0°W and 120°W longitude. Compare with Figure III-1a.

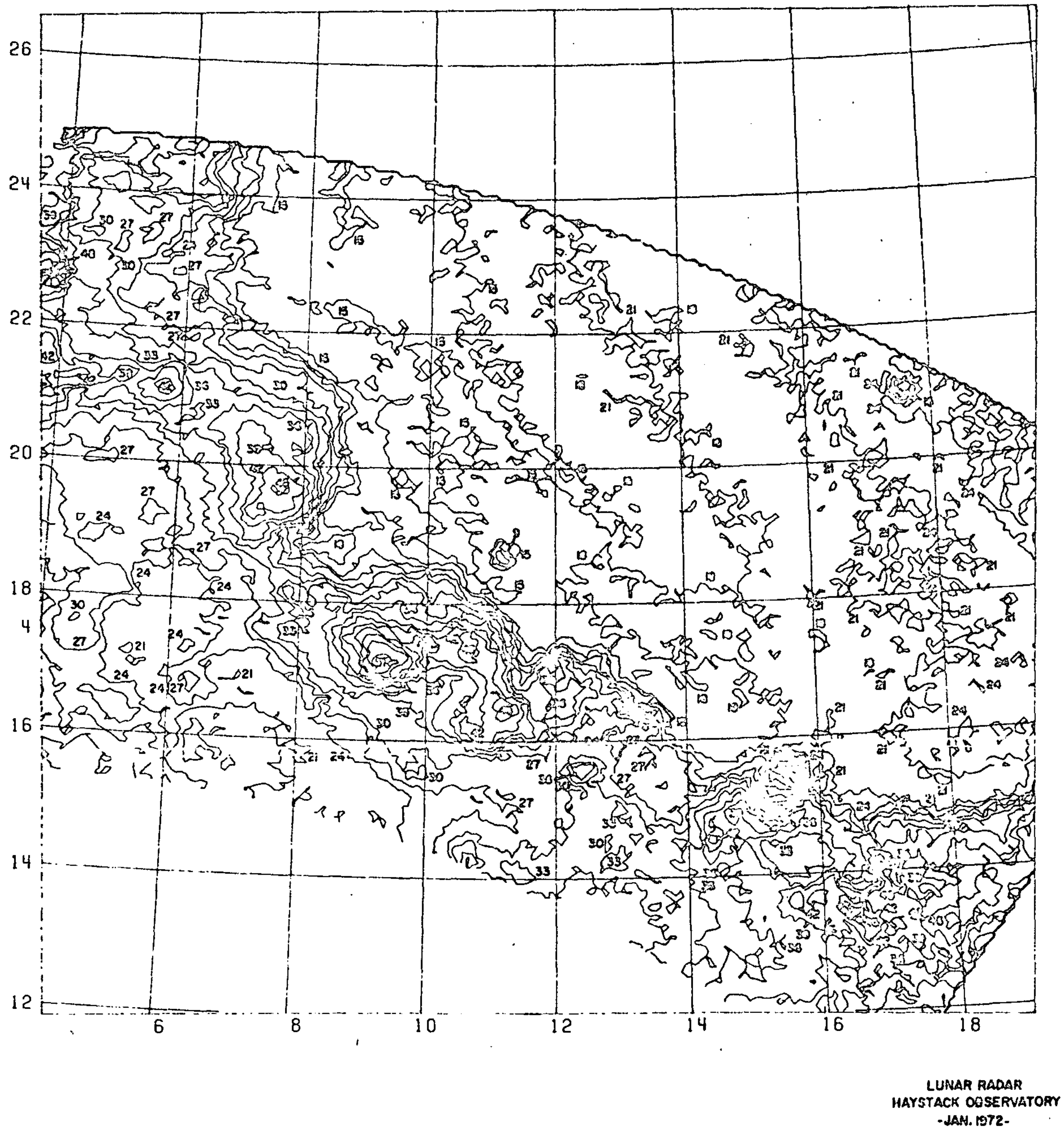

Figure III-2. Southwestern Mare Serenitatis: Radar-measured topography contours. Contours are labeled in hundreds of meters above an arbitrary datum, with 300-meter contour spacing. To orient the map, note the positions of craters Menelaus (15°.4E, 15°.4N and Bessel (17°.6E, 21°N). Note also the 150-km long depression trending NW-SE through the point (E12° N20°) on the Mare surface, and rising ground toward the northeast.

The simple slope-fitting least-squares program, intended for the assembly of a global topography from individual observations, has suffered from the above-mentioned non-linear topography differences. When programming assistance becomes available in about one month, a more elaborate program will be written that will adjust for the discrepancies in the values of lunar position, velocity and librations. The measured data appear to be sufficiently accurate and redundant to permit a satisfactory fit from such a program.

Another, although minor, problem is a shift that appears in the mapped position of elevated features as a result of the parallax between the original radar range-doppler perspective (perpendicular to an Earth-based line-of-sight) and the ultimate map perspective (along a lunar radius). The program to repair this distortion is relatively straightforward, and should be finished in a few weeks.

In the meantime, the topography of selected smaller-scale areas of the moon is being examined for features that reveal something of the recent history of the lunar crust. Results for the Alphonsus-Ptolemaeus-Mare Nubium area (Haystack Quarterly, 15 April 1971) are now complete and are being submitted to <u>Science</u> for publication (S. H. Zisk). The next candidate area is the southern rim and floor of the Mare Serenitatis, particularly because of the dark flow features and possible cindercones noticed from the orbiting Apollo-15 Command-module.

<u>Some Results of Interest</u>

Figure III-2 is a contour map of the radar-measured topography for the southwestern edge of Mare Serenitatis. Several features of the topography are noteworthy, especially since this mare exhibits one of the strongest gravitational anomalies so far measured. The mare surface appears to slope generally upward toward the northeast. This slope may yet be an artifact caused by aforementioned problems with the lunar libration ephemeris , though it has been independently confirmed in three separate measurements of other parts of the mare. All were taken within a few days so that a hypothetical slowly-varying ephemeris discrepancy might possibly cause a consistent error in calculated slopes.

The strongest argument for the reality of this slope, however, appears in a map of the adjacent area to the southeast. There, this prevailing slope in Serenitatis is again quite clear. In the same map, however, large areas of Mare Vaporum and Mare Tranquilitatis also appear, and neither of these show any slope. Not only are both surfaces level, but they also appear to have nearly identical elevations, extending across a 400-km span that is divided by mare rim material! Since topography errors caused by an inaccurate ephemeris should affect an entire map more or less uniformly, it appears from the absence of any such slope in Tranquilitatis and Vaporum that the relative topography for the Serenitatis series of measurements should be accurate to better than 300 meters.

It should be noted that the two maria with constant elevations also show no significant gravitational anomalies, although their average elevation is greater than Serenitatis by at least 2 km. This interesting fact will be considered in more detail below.

Looking again at Figure III-2, we observe another feature suggestive of large-scale plate tilting in Mare Serenitatis. There appears to be a topographic low with a 1500 m. elevation along a line running NW-SE through the point (12°E, 20°N). The slope mentioned in the previous paragraph starts upward from this trough toward the northeast, whereas the mare surface to the southwest of the trough remains approximately level for 30 km to the foot of the mare walls. It is not clear whether the northeast side of Serenitatis has been raised or the southwest side dropped at some time after the surface solidified. Because of the Serenitatis mascon, the uplift may eventually seem more likely, with the mare surface now underlain by a very dense layer that accounts for the mascon. However, if the Tranquilitatis and Vaporum basins were formed much earlier in the moon's history, they may have filled with highly porous dust and breccia before the ultimate lava flows that formed the present surface. Then Serenitatis may have a thicker layer of surface basalt compared to the other two maria, in spite of its lesser elevation.

Such explanations are, of course, highly speculative. One may hope that further examination of the topography of these and other maria will lead to more definite conclusions.

Surface Backscatter Maps

An investigation of earth-based data on the Descartes landing site (Apollo 16) was begun late last year. Two projects are underway: 1) An investigation of the blockiness of North Ray Crater, based on comparisons with the similar radar-bright feature we are calling Flamsteed HOA † (Latitude 2.3 S, Longitude 44.1 W) that appears in a high-resolution Lunar Orbiter V frame. This work has been completed and submitted to Jour. Geophys. Res. (H. J. Moore and S. H. Zisk). 2) Investigations of the geology of the Cayley Formation, on which the Apollo 16 landing is to take place, and of the Bright Descartes Formation 30 km to the south. This work is almost completed and is to be submitted within two weeks to Science (S. H. Zisk, H. Masursky, D. J. Milton, R. W. Shorthill and T. W. Thompson).

S. H. Zisk

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† Haystack Observatory radar feature "A."

D. Radar Instrumentation

A second Varian VA-949 BM, serial number 25, was received and was placed under test by late December. The collector water fitting was not shipped with the tube and the cathode and filament leads could not be tightened without modifications to the fittings. Initial testing under RF conditions indicated that this klystron required considerably more drive than the original VA-949 BM, serial number 22, and that it may be more predisposed to arc problems. However, testing must be completed before final judgment is rendered.

A major modification is under way in the waveguide and switch control configuration in the PR-Box to permit use of both the maser receiver and the new Comtech paramp (see II C 4) at X-band frequencies. Since this work will not be completed until next reporting period, a description of the modifications will be deferred to that report. Availability of the Comtech unit in the PR-Box will further increase the flexibility of the system for radio astronomy use when the PR-Box is on the antenna because of its greater bandwidth and tuning range as compared to the travelling wave maser. Its closed-cycle cooling will also substantially reduce charges for liquid helium.

R. P. Ingalls
M. H. Leavy

APPENDIX

Publications for July - December 1971

Detection of an Unidentified Emission Feature in the Microwave Spectrum of W3
E.J. Chaisson
Astrophys. J. 167, L61-L64 (15 July 1971)

Quasars Revisited: Rapid Time Variations Observed Via Very Long Baseline Interferometry
A.R. Whitney, I.I. Shapiro, A.E.E. Rogers, D.S. Robertson, C.A. Knight, T.A. Clark, R.M. Goldstein, G.E. Marandino, N.R. Vandenberg
Science 173, pp 225-230 (16 July 1971)

Radiofrequency Observations of Symmetric Nebulae Around Wolf-Rayet Stars and an O7f Star
H.M. Johnson
Astrophys J. 167, No 3 (1 August 1971)

Lunar Apennine-Hadley Region: Geological Implications of Earth-Based Radar and Infrared Measurements
S.H. Zisk, M.H. Carr, H. Masursky, R.W. Shorthill, T.W. Thompson
Science 173, No. 3999, p. 808 (27 August 1971)

Detection of Methyl Alcohol in Orion at a Wavelength of ~1 Centimeter
A.H. Barrett, P.R. Schwartz, J.W. Waters
Astrophys. J. 168, No. 3 (15 September 1971)

Search for Extragalactic H_2O
D.F. Dickinson, E.J. Chaisson
Astrophys. J. 169, No. 1, p. 207 (1 October 1971)

High-Resolution Observations of Compact Radio Sources at 6 and 18 Centimeters
K.I. Kellermann, D.L. Jauncey, M.H. Cohen, D.B. Shaffer, B.G. Clark, J.J. Broderick, B. Ronnang, O.E.H. Rydbeck, L. Matveyenko, I. Moiseyev, V.V. Vitkevitch, B.F.C. Cooper, R. Batchelor
Astrophys. J. 169, No. 1 (1 October 1971)

Mapping of Solar Polarization at 7.8 GHz
D.W. Richards, R.M. Straka
Nature Physical Science 233 (4 October 1971)

Broad-Band Passive 90° RC Hybrid With Low Component Sensitivity For Use in the Video Range of Frequencies
A.E.E. Rogers
Proc of the IEEE 59, No. 11, pp. 1617-1618
(November 1971)

Evaluation of the Haystack Antenna and Radome
M.L. Meeks, J. Ruze
IEEE AP-19, No. 6 (November 1971)

Radiofrequency Detection of An Anomalous Interstellar Recombination Line
E.J. Chaisson, J. A. Ball
Astrophys. J. 169, No. 3 (1 November 1971)

The System of Planetary Masses
M.E. Ash, I.I. Shapiro, W.B. Smith
Science 174, No. 4009, p. 551 (5 November 1971)

High-Frequency Confirmation of a Radio Recombination Line From an H_1 Region
E.J. Chaisson
Astrophys. J. 170, No. 1 (15 November 1971)

The Small-Scale Structure of Radio Galaxies and Quasi-Stellar Sources at 3.8 Centimeters
M.H. Cohen, W. Cannon, G.H. Purcell, D.B. Shaffer, J.J. Broderick, K.I. Kellermann, D.L. Jauncey
Astrophys. J. 170, No. 2 (1 December 1971)

Martian Craters and A Scarp as Seen by Radar
G.H. Pettengill, A.E.E. Rogers, I.I. Shapiro
Science 174, No. 4016 (24 December 1971)